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Aviation

TELEMETERING PHYSIOLOGICAL RESPONSES DURING EXPERIMENTAL FLIGHTS

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Introduction

Modern technology has made it possible to transmit to remote locations nearly all physiological responses which involve external electrical, mechanical or thermal changes. With man entering increasingly hostile environments as he approaches space flight the interest in telemetering such data has intensified. Since 1947 the Bureau of Medicine and Surgery has been sponsoring a project on "the transmission of physiological responses from air to ground by electronic methods." Under the program equipment has been developed for telemetering a large variety of physiological responses of individuals in aircraft under operational conditions. Since these facilities were available the senior author has frequently been requested to take responsibility for monitoring the safety of individuals participating in hazardous experimental flights. This paper discusses some of the experiences gained in these operations.

Figure 1 presents in diagrammatic form the basic equipment required for telemetering physiological responses. The electrical changes picked up or produced by electrodes, thermosters, and strain gauges are amplified and fed through subcarrier oscillators. This procedure imposes the voltage changes from each of these transistors upon separate carrier frequencies which are then mixed or combined and after a further stage of amplification transmitted over a standard UHF frequency. At the ground station this transmission is picked up by a receiver, amplified once again and then the subcarrier frequencies unscrambled by the use of a discriminator for each item of information. This information can then be presented on a oscilloscope, over a speaker or by means of an ink writer. If a speaker or ink writer is used a further stage of amplification is required. All information can be permanently stored by recording the signals prior to putting it through the discriminator. Physiological responses from pilots beyond the radio range of the home station can be monitored by relaying information from remote stations to the home station by means of telephone lines. This additional relay procedure permits the recording of physiological responses from any point on earth which is within the range of one radio station.

Quite obviously the transmission of responses over radio lengths involves a number of problems which are not encountered in laboratory electrophysiological recording. Space does not permit a full discussion of these problems, however, several of the primary problems merit mention. The vibration of the plane and the activity of the pilot often make the securing of electrodes more difficult than under normal laboratory circumstances. It is also not possible to electrically shield the subject, therefore electronic noises interfer with the recording. All electronic equipment must be adapted for the aircraft power supply. In addition, since this power supply is less stable than that usually available on the ground, special filtering must be developed. Another significant problem is the carrier band width. The frequency width of the carrier determines the maximum range of frequencies which can be transmitted. Several physiological responses can be placed on the same carrier frequency if, as in the case of the EEG and the EKG, they have limited frequency ranges. On the other hand where a broader frequency spectrum occurs, such as the EMG, fewer measures can be sent with the same carrier frequency. Another problem not generally encountered in the laboratory is that of the size and weight of the equipment. The equipment must fit within the aircraft. Miniaturization of electrical compenents has brought this problem fairly close to solution. Where necessary the weight and space requirements of electronic equipment can be reduced to where they become a minor factor. Radio transmission during poor weather conditions introduces noise into the system. To minimize this, FM transmission is used. A final difficulty in remote recording is that in the case of a poor recording it is not possible to check the leads and connections on the pilot immediately so that it is sometimes difficult to determine the cause of any malfunctioning. Despite these many problems electrophysiological responses, of varied types, have been successfully transmitted for large distances by radio gear. With equipment developed under this program, it is possible to transmit almost any electrophysiological response which can be recorded in the laboratory.

The equipment described above has made possible the study of physiological responses of man and animals during actual flights. Such studies have been directed at the problem of human psychological and physiological reactions to stress. The theroretical approach used in these studies is of stress schematized in Figure 2. This approach divides the problem into three areas: the stressful conditions themselves; the emotional reaction of the individual to these conditions; and the effects of his reactions on his performance. The stressful conditions can be divided into two broad categories: physiological stressors and psychological stressors. The physiological stressors are those physical factors of the cockpit environment such as oxygen and CO_2 tension, pressure and temperature changes of which the pilot may or may not be aware. These physiological stressors generally produce their effects by direct action on the body and its functioning.

For example, hypoxia may produce unconsciousness without psychological awareness. Psychological stressors on the other hand typified by the threat of physical injury, confinement, or the time pressures and complexity of the task required of the pilot, generally produce their effects by provoking within the individual an emotional reaction. Such emotional reactions are accompanied by conscious feelings such as fear, anger, excitement or boredom, and by a physiological energy mobilization which generally results in increased heart rate, blood pressure, reduced gastric motility, etc. If the individual is aware that he is being affected by a physiological stressor. For example, if the individual is aware that his oxygen mask is not functioning properly, he may recognize a threat of physical energy and experience a fear reaction.

The first step in an operational stress research problem is to analyze the stressful conditions to determine which stressors are of most significance in a given situation. Once this is done methods are developed to rate or measure the severity of the stress. Where psychological stressors are involved it is frequently possible to set up ratings of the severity of stress encountered on particular flights. For example, routine training flights may have low levels of stress while operational flights in bad weather or when with live ammunition, etc. may involve high levels of stress. It is generally possible therefore to rank the levels of stress involved in various flights and to compare the reactions of the pilot on each type of flight. In the case of physiological stressors it is frequently possible to make even more direct and accurate measurements. For example, pressure changes and g levels in the aircraft may be measured and telemetered. One a method of measuring or rating the severity of the stressful conditions has been developed attention is turned to the measurement of the pilot's stress reaction. Here two major types of measurements are available. Electrophysiological responses may be made during flights and telemetered to the ground, or blood and urine samples may be taken before and after flights and the change of their constituents measured. Figure 3 illustrates the theoretical mechanism behind these methods. The electrophysiological measurements made during flights are primary responses mediated by autonomic nervous system activity. They give information on the emotional response and the physiological status of the individual during the period of flight. The blood and urine measures primarily reflect the activity of the adrenal, cortex and medulla. These chemical effects are initiated during the period of high stress and persist for some time after the end of the stress. Both types of measures give information on the reactions of the individual to the stresses he has been encountering.

If the stressful conditions are severe enough they lead via either an energy mobilization reaction or a physiological decrement to an alteration in psychological performance. Studies of performance under stress indicate that individuals show extreme variability in their response to stressful conditions. This is true because, on the one hand, individuals vary in their emotional response or the physiological decrement produced by stressful conditions, and, on the other, they vary on the amount a given emotional response or physiological decrement will affect performance. Six major effects of stress produced emotional responses may be noted. One effect of a stress produced energy mobilization is to improve performance on simple tasks are primarily related to the level of energy expended upon them, while the performance of complex tasks is more related to previous learning and higher mental processes which may be upset or interfered with by high levels of energy mobilization. Another effect frequently noted is that large motions may be improved or unaffected by stress while small delicate movements will generally be disrupted by stress. Under stress there is frequently an increase in nervousness and tremors which interfere with fine movement. A further generalization is that under stress there is an increase in speed of reaction, with a decrease in accuracy of performance. The individual is more easily startled; he will react more rapidly but his reaction are generally diffused, not well defined, and therefore reduced in accuracy. The fourth effect of emotional reactions due to stress is that they may reduce the attention to the critical factors for a given test by focusing attention on unimportant or irrelevant factors which are not related to the task the individual is performing. For example, his attention may be focused on his own feelings or on an external source of danger rather than on the task at hand. A fifth effect of stress is that it makes individuals less flexible in their response. Finally, individuals may regress in their behavior to simple more direct approaches to the problem. Since the pilot's task is highly complex, requires fine and accurate movement, complete attention to the task at hand, and flexibility in meeting emergencies, it should be expected that the effect of stress produced emotional reactions or physiological decrement would be to reduce the efficiency of the pilot's performance.

Two approaches are generally open for the measurement of the pilot's performance. Performance of the pilot's mission may be measured. The problem here is that mission success is generally a poor measure of pilot's performance since it is frequently highly dependent on a number of other factors such as weather, aircraft performance, etc. which are not related to pilot's performance. An alternate approach is to give special performance tests to the pilot. Since the pilot is usually fully occupied during the period of the flight itself, such performance tests must precede or immediately follow the actual stress period. A number of psychological tests which have been shown to be sensative to the effects of stress are available for this purpose. The major problem with this approach is that by the time it is possible to make such measurements the stress reactions have frequently disappeared.

The equipment and procedures described above are used for two purposes: first, to monitor the safety of hazardous operations, and secondly, to supplement laboratory stress studies with data on human reactions under the actual environmental conditions encountered in flight. The goal of the operational stress research like that of the laboratory stress research program is to determine the relationship between the intensity of the stressor and the amount of stress reaction (either energy mobilization or physiological decrement) and secondly, to measure the extent to which the stress reaction may affect performance. Monitoring the safety of operational flights requires accurate data on the relationship between the physiological measures which are part of the stress reaction and their effect upon the performance of the pilot. The desire is to detect in advance dangerous physiological conditions which may promote a performance decrement resulting in an accident. The three-part analysis of this stress problem described above appears to be an improvement over many of the approaches to stress used in the past. Frequently, stress studies have considered two of these three phases. The results of such studies are frequently difficult to interpret because the experimenter who does not measure the physiological reactions to stress often fails to demonstrate that his subjects were aware of or affected by the stressors which he applied. On the other hand, some investigators deal only with the physiological reactions to stress. However, since a given amount of decrement or energy mobilization may produce differing amounts of performance decrement, the significance of emotional decrement cannot be evaluated. It should be kept in mind that a certain level of energy mobilization is necessary for the proper performance of many tasks. Therefore, the existence of an emotional reaction in and of itself does not necessarily indicate that the pilot's performance is being adversely affected. The essential question is "is the emotional reaction great enough to produce a decrement of performance?"

Monitoring safety of hazardous flights.

The hazards which confront man in flight are well known. of particular importance are those factors which because of men's limited sensory equipment may incapacitate him without his awareness. An example of this type of hazard is the problem of hypoxia. Man has no sense organ to detect the lack of oxygen. Therefore, he may become seriously hypoxic without being aware that he is in trouble. With the pilot already overloaded with instruments to watch, oxygen gauges and warning systems are only a partial answer to this problem. Where special hazards are expected therefore as in stratospheric balloon ascents telemetering equipment makes it possible to monitor such physiological responses as heart rate, breathing rate, and oxometer readings from the ground. This permits the flight surgeon to detect the first signs of trouble and take appropriate action. In essence the flight surgeon's task is similar to that of the pilot monitoring his engine instruments. The flight surgeon must monitor the pilot's "engine". He must know the normal limits of a man's "cylinder head temperature". When the heart rate exceeds the red line he must take immediate action either to cure the trouble or to abort the mission. If physiological responses indicate a dangerous state within the organism, his duty is to call back the mission. For this purpose "red Lines", or criteria for terminating stressful flights, must be adopted. The problem here is to obtain sufficient amounts of information about the normal variation of such physiological functions as heart rates and breathing rate to establish maximum safe levels to be permitted during the flight. Unfortunately, the experience of Project RAM has indicated that the usual concept of normality does not apply in flight operations. For example, when project RAM was first assigned the responsibility for monitoring the safety of the stratolab balloon ascents, a group of experts in medicine and physiology were brought together to determine the maximum safe levels of heart rate, respiration, and other physiological measures. As a result of this conference, maximum acceptable heart rates were tentatively set at 130 per minute and the maximum safe respiration rates were tentatively set at 30 per minute. However, these criteria had soon to be abandoned. The first operation in which there was an attempt to apply these criteria was a balloon ascent in an open basket through a thunder cloud. Psychologically, this ascent was a highly stressful one since the turbulence and electrical buildup within the cloud presented a definite threat to the operation's safety. EKG and respiration rate recordings from one member of the two-men crew indicated that for this man his heart rate was 180 and his respiration rate 70 per minute before the gondola left the ground. These high rates were maintained throughout the early part of this particular operation. If the original criteria had been enforced, this flight would have been cancelled prior to takeoff!

Another problem encountered in monitoring the safety of an operation is illustrated by the data given in Figure 4. This figure gives the heart rates collected from four experienced pilots as part of the study of stress in operational flying. Heart rate measurements were made both on the ground and during various types of jet flights. The left hand bar gives the average heart rate recorded during daily physicals. These are standing pulse rates taken on the ground. The next bar indicates the average pulse rate for measures taken immediately after return from a jet mission while the pilot was still seated in the cockpit. The third bar indicates the average pulse rate during routine training flights involving no particular stress. The fourth and fifth bars give the average rate during stressful live firing runs and the heart rate at the point of maximum stress in this firing run, respectively. The point of particular interest here is that while the heart rate of all pilots increases to some extent during the flight when compared to standing pulse rate on the ground, the pulse rate of two of the pilots shows a very much larger increase than that of the other two. This large individual difference in reaction to an essentially similar condition makes the application of a set criteria for terminating flights impossible. Rather, criteria specific to the individual must be set up on the basis of a thorough preliminary study of the responses of each individual.

Underlying both the problem that the usual concepts of normal physiological stressors. Hypoxia may produce an increase in breathing rate and an increase in heart rate. However, emotional responses appear to have a much larger effect on breathing and heart rate and therefore are likely to obscure any effects due to hypoxia. This is true even though the measurements are taken on highly experienced successful flyers who would be expected to show a minimum of emotional reactions during flight. It is also important to be aware that despite these large changes in physiological response, the pilots were able to perform this mission with no apparent decrease in efficiency.

Operational research.

There are two basic approaches to the problem of determining the effects of flight on the living organism. One approach might be termed a laboratory experimental method. In this procedure data about the environment encountered in flight are collected by instruments on the ground or in special vehicles such as high altitude balloons, etc. On the basis of these data this environment can be simulated in the laboratory for biological studies. Another, the operational approach, is to place an organism in the plane itself and study its reactions under the actual flight conditions. Obviously these two approaches are not mutually exclusive alternatives. Since each has unique advantages both should and are being carried on at once. The primary advantage of laboratory procedure is the precise control that can be exercised over the environment itself, and the physiological and psychological measurements of the subject's reaction to this environment. Precise control is not possible in the operational approach; however, there are important advantages to this procedure. Most obvious of course is the fact that not all the effects of flight may be simulated in the laboratory. For example, travel in or on the border of space involves weightlessness which cannot be simulated completely in the laboratory. Moreover, in the laboratory it is usually possible to simulate only one or two components of the total flight environment at any one time. An organism may be able to adjust to a partial simulation but break down under the impact of the additional stresses present in the actual flight environment. Nor, finally, can we be sure that all the hazards of such new areas as space flight have been identified. Only survival in space will demonstrate that this new frontier has been conquered.

For the purpose of in-flight research, man is the most valuable subject since it is to him to whom we must apply the data from any experiment. However, where, as in space flight, the hazards are too poorly understood to warrant risking the life of a human being, lower animals may serve as subjects. The man or animal and his compartment serve essentially as a biological instrument on which to record the effects of the environment to be studied. The important features of this equipment as with any mechanical or electronic instrument is its sensitivity, reliability and durability. In addition, because of the limitations of the vehicle, considerations in size, shape, and weight are also important. If the instrument is to be used in or near the borders of space, it will have to be completely self-contained requiring no outside source of energy. Like all instruments this biological measuring device requires calibration. In order to obtain a maximum of information from the physiological and psychological measures available, control data must be collected under normal, nonstressful conditions and under simulated stress of various types in order that the normal and the stress response levels of these measures for each subject will be known in advance. This involves a series of preflight tests under both nonstress conditions and during exposure to such stressors as increased g, reduced pressure, reduced oxygen tension, temperature variations, etc. Typical patterns of reaction under these conditions must be determined. Once determined it is then possible to contrast the telemetered data with these control measures. This preflight control data is particularly important in the case of animals in space vehicles since, at least at first, it will not be possible to return the animal to the ground. In such a case the value of the telemetered data is almost entirely dependent upon the adequacy with which the animal responses have been studied prior to the actual space flight. During the actual operation itself the basic problem is to record the condition of man or animal at all times and to determine whether it is performing up to the expected level. The cause of unexpected patterns of physiological activity or of a performance decrement must be determined against the background of information previously obtained on the characteristic response of the organism.

Summary.

Modern technology has provided means for transmitting to remote locations nearly all physiological responses which involve external electrical, mechanical, or thermal changes. These developments have made it possible to make precise physiological measurements under operational conditions of the type that only a short time ago were limited to the laboratory. Since transmission of these responses is possible, the pilot's physiological reactions may be monitored from the ground in order to protect him from environmental hazards to which he is insensitive. A major problem which arises in connection with this procedure is that emotional responses obscure physiological reactions, resulting in reactions beyond what are normally considered safe and producing large individual differences in reactions. To overcome these problems careful studies of each individual to be monitored must be made prior to the actual experimental flight. Telemetering also permits experimental study of stratosphere and space flights. Here again, control data are essential since in many cases it will not be possible to return experimental animals to the earth and therefore all information on their status in space must be gathered by comparing telemetered physiological recordings with control data collected on the ground.

A SCHEMATIC ANALYSIS OF STRESS REACTIONS

STRESSFUL CONDITIONS

Psychological Stresses

1. Threat of physical injury
2. Task-induced stress
   a. Time pressures
   b. Task complexity
   c. Prolonged work periods
3. Confinement
4. Lack of stimulation

Physiological Stressors

1. G stress
2. Habitability
   a. Oxygen tensions
   b. CO_2 tension
   c. Pressure changes
   d. Temperature
3. Radiation problems
4. Zero gravity

STRESS REACTIONS

Conscious Feelings

1. Fear
2. Anger
3. Excitement
4. Boredom

Physiological Energy Mobilization

1. Measures taken in flight (EKG, EMG, EEG, PGR, Breathing Rate, Skin Temperature, etc.)
2. Change in blood and urine constituents occurring during stress but measured following the flight

Physiological Decrement (Injury)

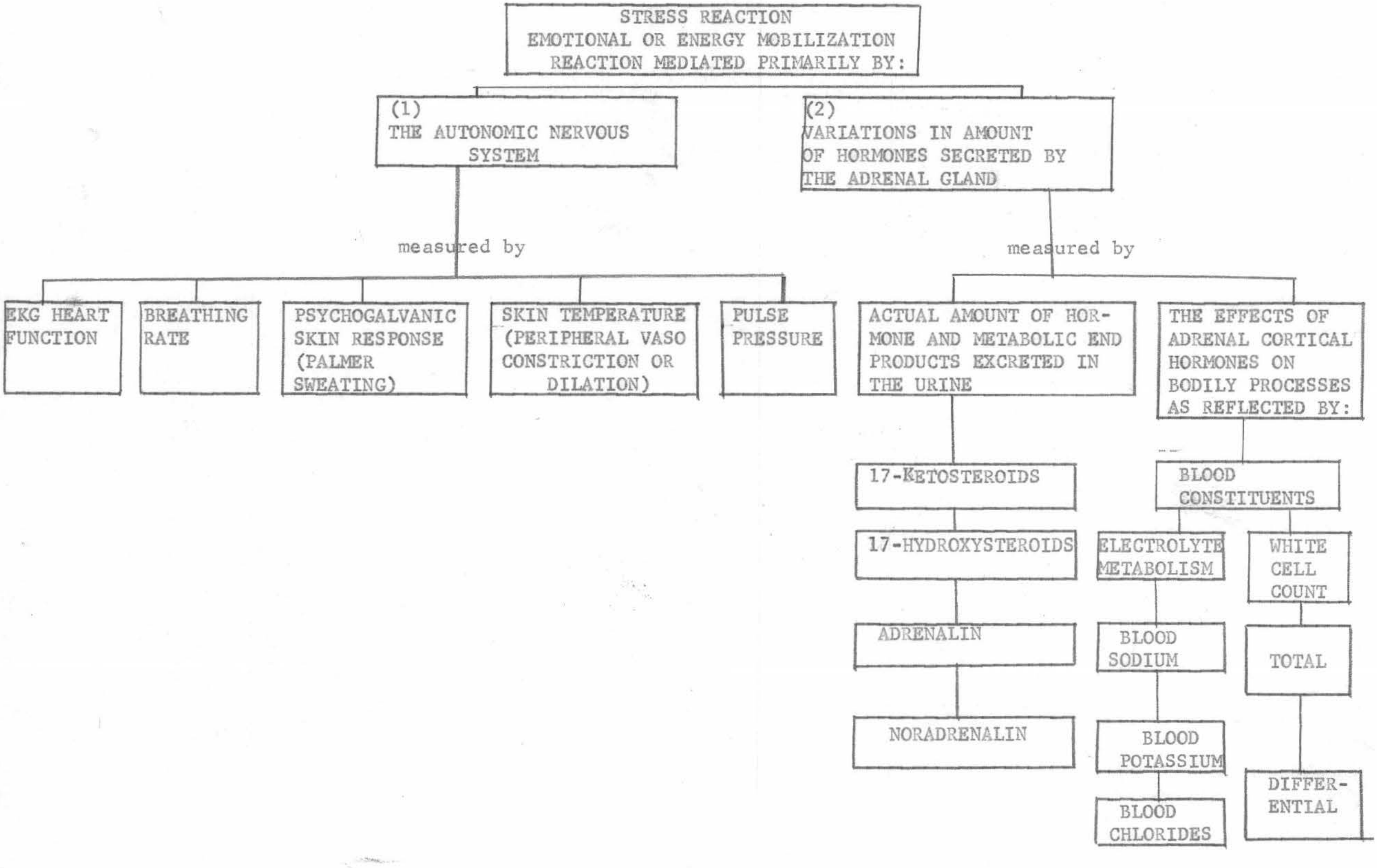
1. Measures taken in flight (EKG, EMG, EEG, PGR, Breathing Rate, Skin Temperature, etc.)
2. Change in blood and urine constituents occurring during stress but measured following the flight

STRESS EFFECTS

Psychological Performance

1. Performance during flight
2. Performance after stress
   a. Flicker fusion threshold
   b. Mirror drawing
   c. Digit span
   d. Digit symbol
   e. Digit addition
   f. Color conflict

Figure 3


STRESS REACTION
EMOTIONAL OR ENERGY MOBILIZATION
REACTION MEDIATED PRIMARILY BY:
(1)
THE AUTONOMIC NERVOUS SYSTEM
(2)
VARIATIONS IN AMOUNT OF HORMONES SECRETED BY THE ADRENAL GLAND
measured by
measured by
EKG HEART FUNCTION
BREATHING RATE
PSYCHOGALVANIC SKIN RESPONSE (PALMER SWEATING)
SKIN TEMPERATURE (PERIPHERAL VASO CONSTRICTION OR DILATION)
PULSE PRESSURE
ACTUAL AMOUNT OF HORMONE AND METABOLIC END PRODUCTS EXCRETED IN THE URINE
THE EFFECTS OF ADRENAL CORTICAL HORMONES ON BODILY PROCESSES AS REFLECTED BY:
17-KETOSTEROIDS
17-HYDROXYSTEROIDS
ADRENALIN
NORADRENALIN
BLOOD CONSTITUENTS
ELECTROLYTE METABOLISM
WHITE CELL COUNT
BLOOD SODIUM
BLOOD POTASSIUM
BLOOD CHLORIDES
TOTAL
DIFFERENTIAL